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Economics of agroforestry: links between nature and society

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Introduction

Climate emergency and rural poverty, especially in developing countries, call for a shift to new paradigms regarding farming practices and the relations between farmers (including *(agro)forest* farmers) and nature. Agroforestry is an emblematic agricultural model that combines trees and plants export products (rubber, clove, timber, resins…) and food production, with ecosystems services, such as carbon capture. However, dissemination of the benefits of agroforestry still faces path dependency in innovation processes (van Noordwijk 2021; Martin et al. 2022). Agroforestry systems still lack of both economic and technical field realities, as well as a better understanding of *(agro) forest* farmers' practices, strategies and perceptions. Although agroforestry has been practiced for millennia, it remains a relatively young and widely open field of research due to the importance of the context in which agroforestry practices are developed.

This special issue drew mainly from papers presented at the 4th World Congress on Agroforestry in France in 2019. It is intended as a contribution on the economic dimensions of agroforestry, embracing several scales, from the plot to the state, and several levels of socio-productive complexity. Through a pool of study cases carried out in several countries from four continents (Africa, Asia, Europe South America, and United States) the authors bring new light on the economic benefits of agroforestry, the need to improve its development worldwide, and the main socio-political determinants that explains agroforestry within territorial dynamics.

Fourteen papers were accepted for the special issue. We sorted the papers into three groups.

A first group of papers focuses on the role and significance of the positive externalities provided by agroforestry, especially trade-offs of intercropping, compared to other agriculture practices. Intercropping' is a practice used to diversify crops in agroforestry systems. Literature often highlights that agroforestry supports a diversity of production systems but what is really at stake? Addressed questions include: what are the trade-offs between crop diversity and productivity, or between crop diversity and management strategies? What thresholds and conditions to achieve an economic profitability?

A second group of papers explore the short, mid and long-term consequences for farmers' organizations. A topical question addressed is: what does agroforestry adoption change in terms of cash flow, income and wellbeing?

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A third group of papers brings new elements of reflection on methodologies developed to understand the impact of public policies and long-term trends (such as market trends) in the emerging and spreading of agroforestry systems in the world. These papers often combine social sciences approaches such as sociology, ethnology or geography, with more classical method of economy. Trans-disciplinarity is thus emphasized to better understand the complexity of processes involved in agroforestry implementation by the farmers, but also to experiment and improve participative and action research.

Agroforestry and the intercropping economic trade-offs

Four articles focused on the economic trade-offs of agroforestry versus other agricultural systems. Multifunctionality of annual/perennial intercropping with trees has been demonstrated to help diversify sources of income, provide bioenergy, shade for pasture and animals, wind, soil and water protection, etc. However, the intercropping implementation raises some technical questions (e.g., density, time of profitability). In Croatia, for instance, there is a growing interest in walnut orchards for nut production on arable land, but the long-term investments required may dampen farmers decision for planting (Žalac et al. 2021). The authors propose a biophysical simulation model tool (Yield-SAFE) to determine the growth and yield of crops and trees in arable, orchard, and silvoarable systems, and an economic farm model (Farm-SAFE) was used to assess their profitability. They show that intercropping is more productive than separate arable and walnut production for all tree density scenarios. Their results suggest that silvo-arable agroforestry is a profitable approach to establishing walnut orchards. In England, Smith et al. (2021) address the question of profitability of boundary hedges, planted for bioenergy. They used a simulation model (FarmSAFE) for a financial assessment using data generated from several trials (standards vs alternative hedgerow management) and scenarios for wood-fuel production over a 60-year time horizon. In the northwest Ethiopian highlands, trees such as *Acacia decurrens* are also intercropped, as shown in a study carried out by Mulatie Mekonnen et al. (2021). They investigated the productivity and economic benefit of the *Acacia decurrens* based Agroforestry land use system in small-scale farms. Acacia *decurrens* intercropped was found to provide better income for small-holder farmers. These results can help to draft recommendations on mixed land use system in the study region and broader in similar conditions. In Central Asia, wind breaks have a long tradition but suffered a decline in the 1990s due to a massive cut down for fuel wood (Thevs and Aliev 2021). The authors present a financial analysis on most popular windbreak systems combined with wheat, barley, corn, alfalfa, cotton, and rice in Kyrgyzstan, based on interviews and field observations. The results show that not all the combinations are economically profitable; multiple tree rows shelterbelts did not result in financial gains for most crop tree windbreak systems compared to open field conditions, while single tree line windbreaks are cost neutral.

Articulation of different times scales to understand farmers strategies for Agroforestry

Seven articles focused on the economics of farmer's strategies and tried to articulate short, mid and long terms in agroforestry farmers practices and strategies. On the one hand, and at the farm level, prominent short-term issues were cash flow – day to day farmers and their family's needs, or workload and labour requirement especially when allocating work force for planting and caring for young trees before harvest (immature period). Then consideration must be made for midterm and economic return in the long term. Long term issues of agroforestry, and its economic profitability, strengthens relations between agrarian dynamics and especially agricultural public policies.

Huang et al. (2022) provide a systematic review examining narratives of economic outcomes of the mature rubber production systems. They found that monoculture rubber production may produce higher income in the short term especially when rubber prices are high. However, they report economically advantageous systems appeared to be rubber combined with species which provide additional income in the medium to long term (e.g., sheep and high value timber) and/or enhance ongoing cash flow with a lengthy productive lifespan and regular harvests in other fruit species (e.g. durian and G*netum*). However, these systems are subject to many constraints

such as labour availability, investment and management capacity and market conditions for secondary products. Frey et al. (2021) explore research on the producers, production, marketing, and sales of NTFPs in the United States, including the continuum of production from wild-harvesting to forest farming of NTFPs, and their costs and benefits. They show that integrating NTFPs into forest management can enhance economic opportunities but also will increase complexity, and will entail balancing multiple and potentially conflicting objectives among a diverse community of stakeholders.

In Sri Lanka; Forest gardens (FGs) are tree-dominant land uses in farming systems. Melvani et al. (2020) compared Forest gardens financial performance with other farming systems components in the short-term (reference year, 2012–2013) and long-term (beyond 2013). They show the importance of FGs to food and fuelwood self-sufficiency in the short term but also over time provide the Net Realisable Value (NRV) across all land uses. Since FGs occupied 68% of the study area, their substantial biological and land assets had high non-Current asset values. The authors provide a method to assess the financial viability of forest farming systems that could be recognized in national economic performance assessments.

Transdisciplinary methodological approaches have been developed to understand the socio-economic determinants of transformations in agroforestry systems (AFS) over time, and the public policies impact on them. For instance, Pedelahore et al. (2022) present a method based on the analysis of diachronic data collected at three levels: country, region and farm. It offers a new method of spatiotemporal triangulation, making it possible to identify and classify the main socio-economic determinants of these transformations. Examples of Cameroonian cocoa-based agroforestry systems are given and show that upturns and slowdown of cocoa-based agroforestry systems are first linked to farmers labour force and investments, and secondly impacted by the sector vitality or the aging of the cocoa trees and the yield decline. Sanial et al. (2022) confirm that Ivorian cocoa-based agroforestry systems are shaped by human management of associated trees and that ecosystem services are weakly linked to environmental variables. Trees in these systems provide different services: remnants stock provide most above-ground carbon, but recruits are the most diverse and provide medicinal resources while planted trees are mainly for food resources. These multiple functions of trees, as far as the role of preserving remnants must be considered for climate mitigation and for allowing the survival of the species throughout several cycles of perennial crops.

In Madagascar's east coast, where Agroforestry systems are ubiquitous and structure the landscapes, French colonial policy was also determinant in the AFS dynamics (Mariel et al. 2022). In the past century French colonial government required farmers to produce industrial crops for export, thereby triggering the production of coffee at first, then cloves. Farmers gradually abandoned slash and burn cultivation (*tavy*) mainly for these compulsory crops, paving the way for an economy based on trade and the monetization with a significant positive impact on agricultural income. Boubacar et al (2022) demonstrate that the economic importance of fuelwood in family resources is not a sufficient trigger for farmers to restore their parklands in Niger. Declines in public support and investing in parkland enrichment also significantly impact local arrangements for the multi-use governance of the parkland resources. The low density of young trees indicates that during the past decade, there have been fewer efforts to enrich parklands compared to the 1980s, when Assisted Natural Regeneration (ANR) projects were first implemented. The 3 parklands studied are in the process of becoming severely degraded because dead old trees are no longer replaced through ANR which has implications for villager's interest in sustainable management of natural forests.

Enhancing agroforestry and multiple uses of forest: methodologies, adoption and engagement

Three articles focus on the importance of farmers' perceptions, practices and strategies towards agroforestry but also on participative methodologies aiming at engaging farmers and researchers in the seek for alternatives and socio-technical solutions.

Gosling et al. (2020) designed a method that couples rapid rural appraisal and normative optimisation techniques to determine favourable land-use compositions for meeting various socio-economic and ecological goals, based on farmers' empirical knowledge and preferences, involving smallholder farmers

in Eastern Panama. She found differences in farmers' perceptions and provides valuable information about potential acceptability of agroforestry among them. Resque et al. (2021) assessed ecosystem services from the point of view of farmers, by designing and using a Role-Playing game in the northern Brazilian Amazon. The game was developed using a co-construction process that mainly included farmers, students and researchers. The results showed that game sessions showed how the provision of ecosystem services, through agroforestry systems, as well as other factors (e.g., values, availability of factors), is considered in planning the spatio-temporal configuration of the agroecosystem and associated agricultural practices. Thus, the Role-Playing Game allowed stakeholders to synthesize and discuss different types of knowledge about this process and brought a new light on ecological management of agroecosystems and solutions that are in line with local expectations. In the French West Indies social innovation is critical in shaping human-forest relationships. Farmers and scientists engage with each other to design sustainability transitions. Barlagne et al. (2021) designed a participatory stakeholders' engagement platform to draw on local farmers' knowledge and experience in identifying sustainable pathways for the development of multi-functional agroforestry in Guadeloupe. Results show that while farmers envision prosperous multifunctional forest farms in the future, they must face complex challenges that require solutions at multiple scales and suggest different types of innovation: social, institutional, market-based and technical. Farmers saw themselves as being part of the socio-ecological system and as custodians of the natural environment. These findings question the opportunity for an innovation ecosystem thinking approach that integrates better the agricultural and forestry sectors, but also between actors and scales of governance. Embedment of the stakeholders' platform and its enabling processes in the innovation ecosystem is key to achieve those objectives.

Conclusion

The study of the economics of agroforestry provides a wide range of topics and research showing evidence of the complexity of the links existing between nature and society. History, knowledge, know-how and agroforestry systems change depending on local contexts, price evolution and volatility. Agroforestry is not a panacea adaptable to everywhere as it is often a product of history and particular adaptation between soils, climate, crop opportunity (for self-consumption and now more and more for local or export markets), markets and global adaptation to local specific constraints. But agroforestry when it is adopted and developed, provides a range of technical solutions with significative impact on farmers' incomes, countries' exports, contribution to national richness, as well as improved well-being. Agroforestry patterns display a wide gradient from re-introducing diversity in complex cropping systems (intercropping/tree associations) to forest management and Non-Timber Forest Products (NTFPs) gathering. Biodiversity might be high (jungle rubber, complex multi-scale agroforestry systems) or low (simple agroforestry systems such as coffee under shading).

Indeed, several projects located in tropical forests show an intensification of production practices, from gathering to a diversity of cultivation practices, that questions the definition of agroforestry and may push the frontiers between two scientific communities. For example, contributions of NTFPs to household economies (with example in the United States), shows the continuum of production from forest farming to wild harvesting of NTFPs, and their costs and benefits. Economics show that income diversification is becoming a way to acquire better resilience in a world dominated by uncertainties and commodity prices volatility. There is still much to learn about economic and social impacts of agroforestry. We argue that such a holistic approach will help understanding the complexity of agroforestry in the field, will provide evidence of agroforestry benefits and will evidence social practices and dynamics in the short, mid and long term.

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